Final Technical Report For NASA Grant NAG-5-2528 Iron Line Diagnostics of Narrow Emission Line Galaxies

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This report describes the activities at Penn State University supported by NASA Grant NAG-5-2528, "Iron Line Diagnostics of Narrow Emission Line Galaxies". Initiated at Penn State in March, 1994, the aim of this investigation was to accurately measure the iron (Fe K) line emission in two X-ray selected Seyfert 2 galaxies (NGC 2992 and MCG-5-23-16). The astrophysics being probed was to determine whether the Fe line was narrow, broad or both. The broad line component is very important as a probe of the nature of the innermost accretion onto the central engine in AGNs.

ASCA carried out observations of both sources and we have submitted papers for publication in the Astrophysical Journal for both.

The NGC 2992 data were published in the February, 1996 Astrophysical Journal, with the following reference:

"X-ray Reprocessing by a Molecular Torus in the Seyfert 1.9 Galaxy NGC 2992," K. A. Weaver, J. Nousek, T. Yaqoob, R. F. Ap.J., 458, 160-171 (1996)

The abstract states the conclusions: "We present new X-ray spectral data for the Seyfert 1.9 galaxy NGC 2992 obtained with the Advanced Satellite for Cosmology and Astrophysics (ASCA). These data are combined with archival and published data to outline a 16 year history of flux variability in the X-ray band. We find that, while the 2-10 keV flux has decreased by a factor of $\sim$20 in 16 yr, the flux of the Fe Kalpha fluorescence line has decreased by only a factor of 2-3, and the inferred amount of Compton reflection is 5 times stronger compared to the continuum than 16 yr ago. From the delay in the response of the Fe K line and inferred Compton reflection to decreases in the continuum flux, we estimate that the reprocessed flux lags the continuum flux by 10 yr, giving a distance of $\sim$3.2 pc to the reprocessor. The observed time delay, along with the fact that the Fe K line is narrow (<6600 km/s FWHM), essentially rules out reprocessing in accretion disk. This implies the existence of dense, neutral gas with NH$\sim$ 10^{23}- 10^{25} cm^{-2} within the central regions of the galaxy in addition to a disk, as might be expected for a molecular torus. We find that the flux in the 0.1-4 keV soft X-ray band has decreased by a factor of 15 in 14 yr, similar to the flux in the 2-10 keV band. In addition, the ASCA data, when combined with prior spectral results, imply the presence of a soft excess that is well modeled with partial covering of the nuclear continuum source. We have searched for and found no significant evidence for extended X-ray emission in the ROSA T HRI image of NGC 2992. This lack of extent, coupled with the observed long-term variability of the soft X-ray flux and spectral results for the soft excess, imply that the soft X-ray emission from NGC 2992 is nuclear in origin and is not due to scattering."

The MCG-5-23-16 data were submitted to the Astrophysical Journal, in April, 1996 with the following reference:

Weaver, K., Nousek, J., Yaqoob, T., Mushotzky, R.F., Hayashi, I. and Koyama, K. "The Complex Iron Kα Line Profile in MCG -5-23-16", Ap.J. submitted (1996)

The submitted abstract describes the work: "We report a remarkabe Fe Kα fluorescence line profile in the Seyfert 1.9 galaxy MCG-5-23-16. The line is complex, consisting of a narrow core located at the galaxy's systemic velocity and wings to the red and blue sides of the core. This represents only the second determination by ASCA of an Fe Kα line profile with significant broadening blueward of 6.4 keV, consistent with Doppler boosting. The line core has an EW$\sim$60 eV and the wings have a combined EW of $\sim$200 eV. The entire profile cannot be easily modeled with an emision line predicted from standard accretion disk theories. Instead, the line is marginally triple-peaked and is best described with three Gaussians having rest energies of $5.37^{+0.23}_{-0.19}$ keV (FWHM=30,200 km/s), 6.37$\pm$0.04 keV (FWHM<6,600 km/s), and $6.58^{+0.35}_{-0.38}$ keV (FWHM=75,300 km/s). The line can also be modeled with a narrow Gaussian at $\sim$6.4 keV and an emission line from an accretion disk viewed at an inclination angle of $\sim$25° to 70°, depending on the ionization state of the gas. Within the context of the unified model, the most likely physical description of the complex profile is a superposition of an emission line from an accretion disk and a line that arises far from the disk in either the obscuring torus or the broad line region. This represents the first clear evidence for emission from two distinct X-ray reprocessors within a single Seyfert 1-type galaxy."